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EXPERIMENTAL CHARACTERIZATION OF A HEAT PUMP WATER HEATER USING PHASE CHANGE MATERIAL BY EN 16147 CONTINUOUS DRAW-OFF TESTS AND DAILY LOAD PROFILES

Summary

This paper presents results from testing a prototype heat pump water heater in accordance with EN 16147, including continuous draw-off tests and standardized 24-hour load profiles (water tapping pattern). Unlike conventional systems, which use hot water as the storage medium, the investigated prototype uses phase change material (PCM). The prototype successfully passed the EN 16147 test for load profile L. However, the charging and discharging behavior of the PCM storage differs markedly from that of conventional water tanks. In particular, the useful storage energy defined in EN 16147 depends strongly on charging and discharging power, as well as on the frequency of water draw-offs and the duration of pauses between them. These findings indicate that, although standardized tests are useful for characterizing performance under realistic use-case scenarios, they are not fully suitable for direct comparison with conventional water-based storage systems.

Keywords: heat pump water heater, domestic hot water generation, propane heat pump, phase change materials

Field of application for the findings: domestic hot water generation via heat pumps

Addressed audience: Theme 08. Thermal Energy Storage

1. Introduction

Heat pump water heaters (HPWHs) significantly outperform conventional thermal energy storage (TES) tank-type electric and gas-fired heaters in terms of energy efficiency [4]. Domestic Hot Water (DHW) preparation requires high power draws over short durations. For instance, for tempered draws, where hot and cold water are mixed to reach a comfortable end-use temperature of 40°C, heating water from a mains temperature of 10°C to 40°C requires 8.4 kW at 4 L/min and 25.1 kW at 12 L/min. These values align with typical design flow rates in European standards for showers (6–12 L/min), baths (8–12 L/min), and kitchen sinks (4–12 L/min). Since direct water heating is not feasible with current HP technologies, a storage tank is required, typically filled with water. Recent developments in integrating solid/liquid phase change materials (PCMs) in HPWHs, enhance storage capacity and enable better load shifting during peak demand [4]. The key metric for these solutions is the thermal power over time for heat exchange between the PCM and water, given the inherent heat transfer limitations of PCM.

However, reports on the design and experimental evaluation of TES using PCM for DHW generation remain scarce, particularly those detailing achieved heating rates and/or the amounts of heated water produced under realistic draw-off or tapping conditions. Most studies focus on copper tube and aluminum fin heat exchanger (HEX) designs, with fewer considering aluminum compact plate-fin designs. These studies typically assess storage performance using European useful hot water or load-profile methods, based on EN 16147 or EN 12977-3 /EU 814/2013 , or US DOE first-hour rating procedure. Only Frazzica et al. [3] and Emhofer et al. [1] explicitly considered intermittent tapping cycles or standardized load profiles, which better represent real DHW use compared to continuous draw-off tests. Frazzica et al. [3] also showed that 45–60-minute tapping pauses enabled thermal recovery and reheating, extending hot water delivery.

This contribution reports the experimental characterization of a prototype HPWH utilizing solid/liquid PCM shown in Fig. 1. The unit is designed as a standalone decentralized system for installation in bathrooms or kitchens of individual apartments in multi-apartment buildings. Each apartment is assumed to be connected to a low-temperature underfloor heating network, which serves as the heat source for the HPWH, connected to the supply line at 35°C.

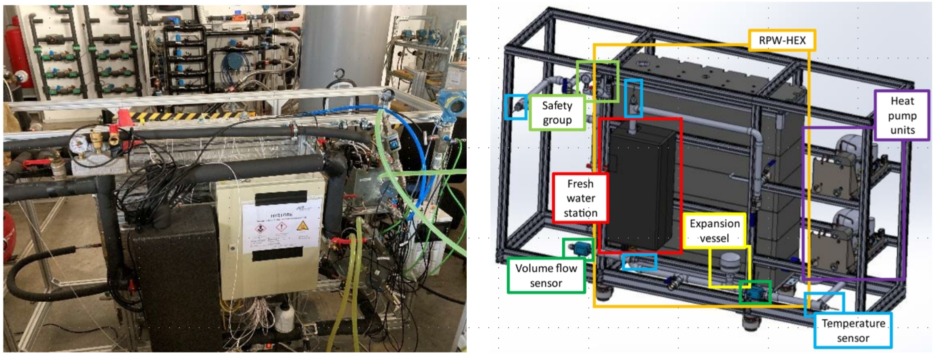

Fig. 1: Photo (left) and 3D drawing (right) of the prototype HPWH utilizing solid/liquid PCM.

The PCM storage is charged directly by two HP modules integrating the condenser HEXs in the storage. The HPs run at fixed compressor speed with a nominal heating capacity of 3 kW. R290 (propane) is used, owing to its low global warming potential (GWP=3), and favorable thermodynamic properties; however, its application is constrained by its A3 safety classification, which denotes high flammability. The need for a low refrigerant charge favors compact components, such as small compressors, valves, tubing, and HEXs. Micro-port extrusion (MPE) tubes, typically made from alloys, have low internal volume and are a cost-effective alternative to aluminum compact plate-fin condensers. In contrast, copper tube/aluminum fin designs are heavier, have higher internal volume, and are more expensive, but offer better thermal conductivity and compatibility with direct DHW contact.

The proposed storage HEX utilizes a brazed plate-fin design with aluminum MPE tubes. Refrigerant tubes, water tubes, and fins are joined by established vacuum-brazing technology. To ensure hygienic DHW preparation, the DHW circuit is separated from the thermal storage via a secondary loop, implemented through a commercial fresh water station.

2. Performance Tests

The unit is tested with two different PCMs, see Table 1 for a summary of their properties and storage data.

Tab. 1: Storage capacity for the two PCMs used in the HPWH.

PCM	**RT60HC**	**SP58**
material class	Ether	Salt-hydrate
latent heat of fusion	210 kJ/kg	220 kJ/kg
thermal conductivity	0.2 W/(m·K)	0.6 W/(m·K)
density (liquid)	0.75 kg/L	1.4 kg/L
mass/ volume	112 kg/ 150 L	225.5 kg/ 160 L
total capacity incl. container (theoretical 40–70°C)	9.32 kWh	18.45 kWh

Different test methods, as outlined in EN 16147, were used:
T1: Useful energy and electrical energy consumption for daily tapping considering load profile size L;
T2: Maximum amount of mixed water at 40 °C for a continuous draw-off (constant-flow) test.

For T1 and using SP58, results indicate that the unit successfully meets the requirements of load profile L. The test, conducted with water flow rates between 3 to 10 L/min, yields a final cumulative energy drawn of 12.5 kWh, which exceeds the minimum requirement of 11.655 kWh of useful energy (EN 16147). The water drawn during the draw-off periods exceeds 40 °C, which defines the lower threshold for useful water (and energy). The maximum draw-off occurs at 08:05, with 3.605 kWh at 10 L/min, and is repeated at 21:00, both requiring power greater than 20 kW. The measured peak power exceeds 30 kW.

In the constant draw-off test T2 at 10 L/min a useful energy of 5.4 kWh is drawn, corresponding to V_{40} = 156 L of mixed water at 40 °C. This confirms that the system meets the requirements for load profile L, which demands 130 L at 10 L/min, as defined in EU 814/2013. Interestingly, the same phenomenon of thermal recovery and reheating is observed as reported by [3], see Fig. 2. When the draw-off is stopped and the water temperature drops below 40 °C, pausing for 30 minutes (without recharging the storage) and then resuming the continuous draw-off allows an additional amount of useful mixed water to be drawn at temperatures above 40 °C. As a result, at 10 L/min the useful energy increases from 5.4 kWh to 7.3 kWh, corresponding to an increase in V_{40} from 156 L to 209 L. This phenomenon extends the hot water delivery by 34%.

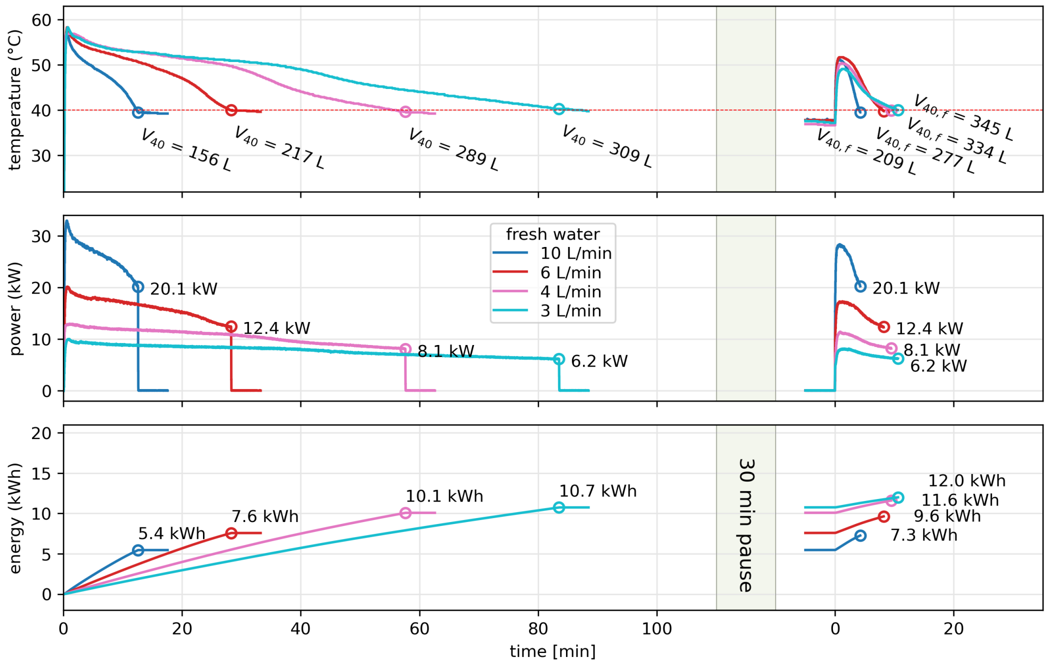

Fig. 2: Energy and mixed water at 40 °C for continuous draw-off (constant-flow) tests at 3, 4, 6, 10 L/min, EN 1647 [2]. After initial charging, the HPs are not active.

3. Outlook

The presentation will address the system design, the implementation of standardized testing protocols, the measured HP performance, and, in particular, the reheating phenomenon as a function of flow rate and pause duration variations.

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